MOSFET Based ECG Signal Acquisition System Design

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By

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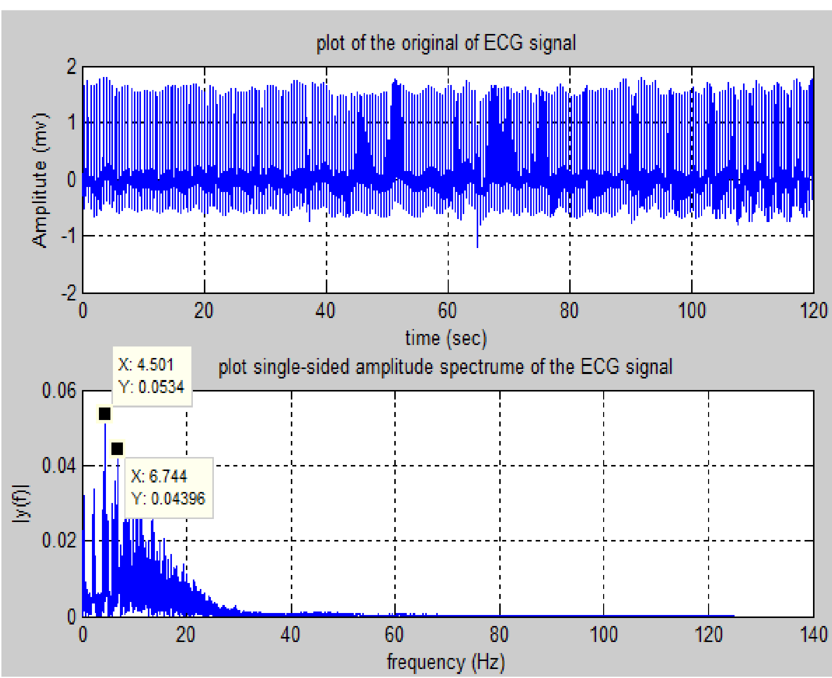
Introduction:

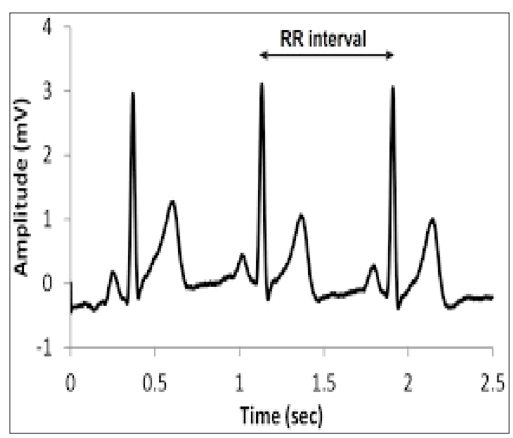
In recent years, cardiovascular disease is one of the main diseases that threats to human life. According to statista **28.1% of total deaths in India are due to the cardiovascular diseases.** Therefore, the prevention and diagnosis of cardiovascular disease becomes one of the primary issues that the medical profession faces today. The medical profession can already make early prediction and diagnose of the related lesions through the study of ECG pattern on time. Therefore, acquisiting and analyzing ECG signal accurately has important meaning.

Digital equipments are nowadays largely preferred to analogical ones especially due to thei r highquality and flexibility of working with their output. Digital signals allow very high signal processing capabilities, easy storage, transmission and retrieval of information. So, it is very important to convert the ECG signals to the digital signals so, analyzing it become easy and accurate.

Basic characteristics of ECG signal:

The ECG signal is a bipolar low-frequency weak signal. According to the standard of the ECG institution of the USA, normal ECG signal frequencies vary in the range of 0.05-100Hz, mainly concentrate in the range of **0.05~ 25Hz** and their amplitude ranges from 10 μ V to 4mV whose typical value is **1mV**.

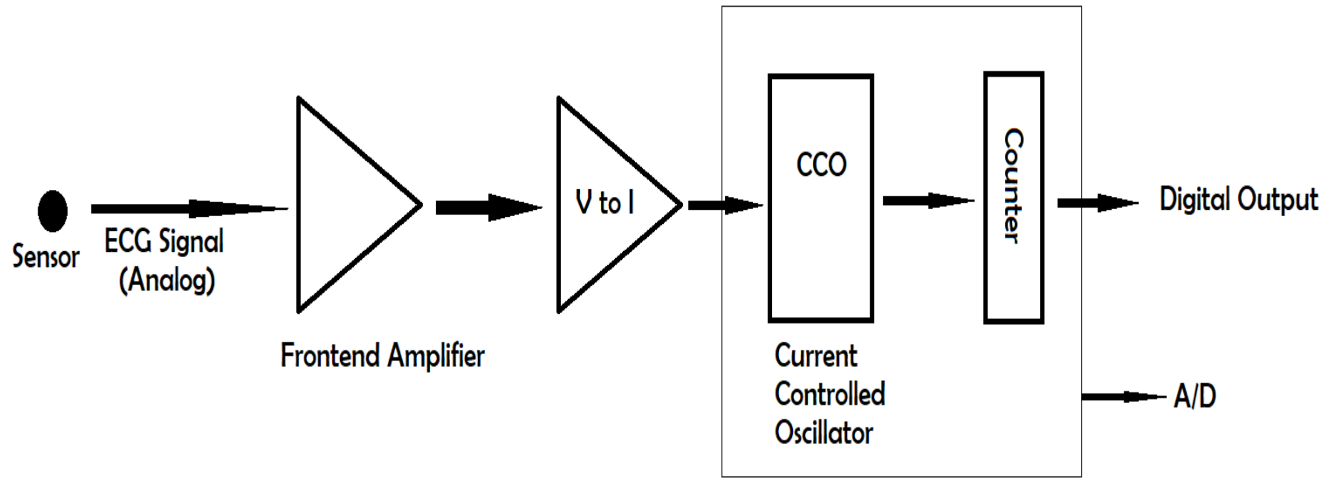




We have proposed a circuit for conversion of ECG to digital signal using MOSFETs because it has low power consumption to allow more components per chip surface area, they are easy to manufacture and widely available.

Design of ECG signal acquisition circuit:

The ECG signal acquisition system includes input sensor (to get ECG signal from human body), Frontend Amplifier (to amplify the input signal of milivolts to few volts), Voltage to Current converter, Current Controlled Oscillator (whose frequency depends on input current) and a counter (which counts the number of waves in a particular time interval).

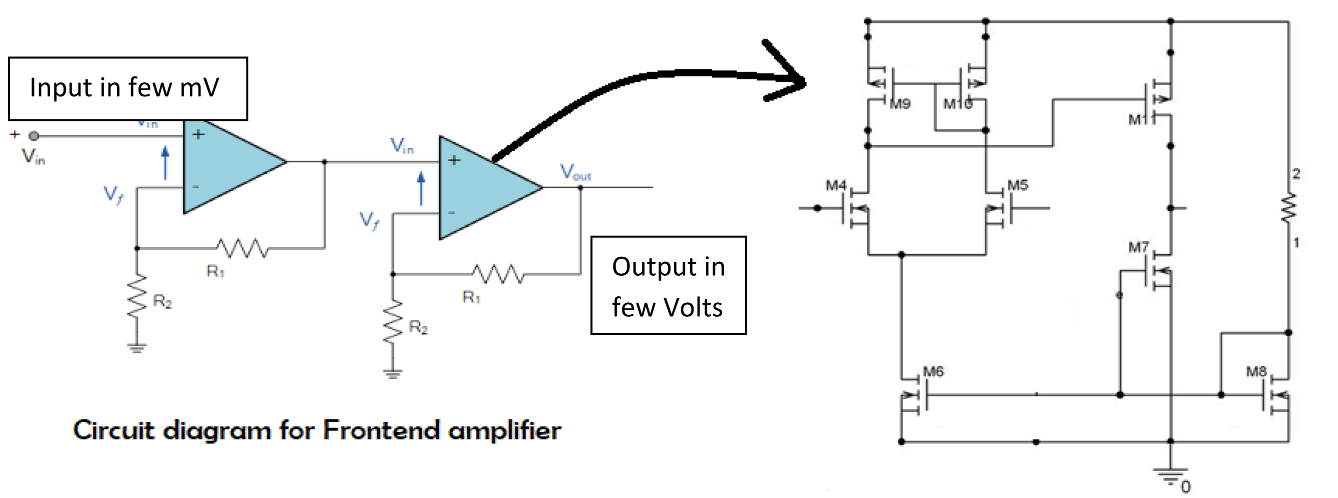


Overall circuit design

[1]- Frontend Amplifier-

As ECG signal has very small amplitude (few mV), it is necessary to amplify them before processing them further. So, we will use a frontend amplifier with two stages for this.

The figure below shows the overview of frontend amplifier.



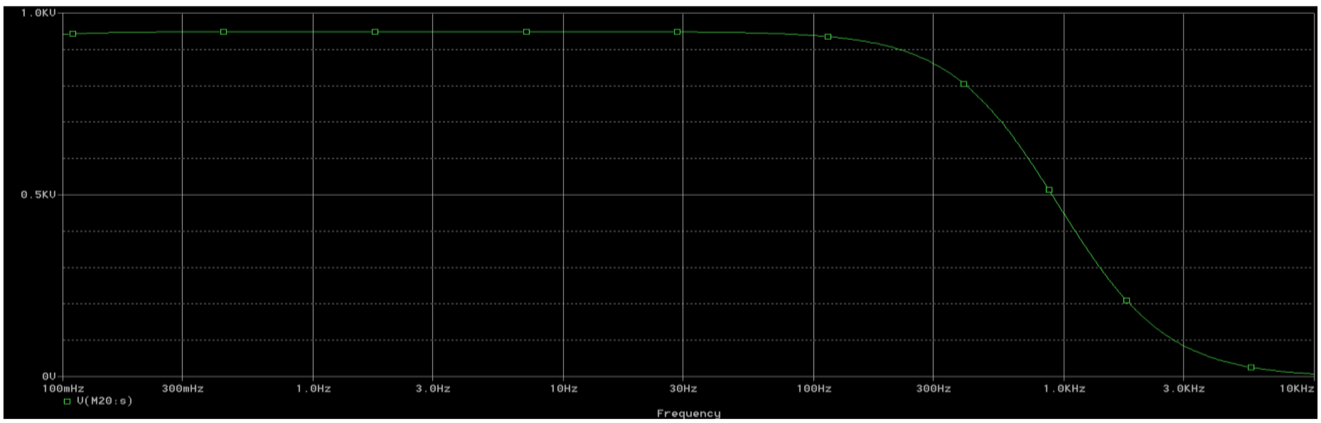
Circuit diagram for Frontend amplifier

We have used 2 stage cascaded amplifier because we have to convert few mV to few Volts so we need a gain of around 1000 but this will not be possible through a single amplifier. So, we used two cascaded amplifier to achieve our goal. An offset of 4.85 volt is also provided to the input.

We have used differential circuit of Op-Amp made of Mosfets.

The gain of one amplifier A = 1 + (R1/R2), which is around 30.6. So, overall gain of our amplifier is around 940.

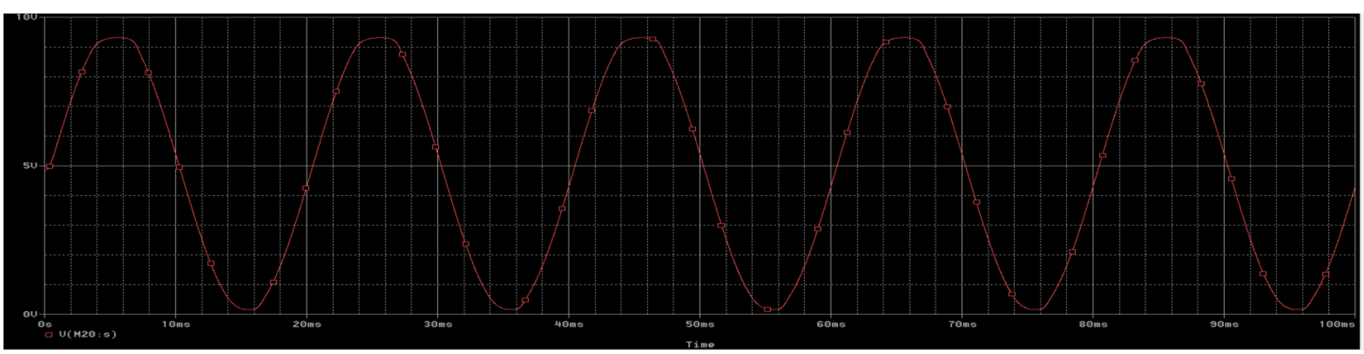
We are able to generate a constant gain of 940 for a frequency range till 100 Hz and our ECG signal contains a maximum frequency of 50Hz so we can safely use our frontend amplifier on ECG signals.



Input range-10uV – 5mV

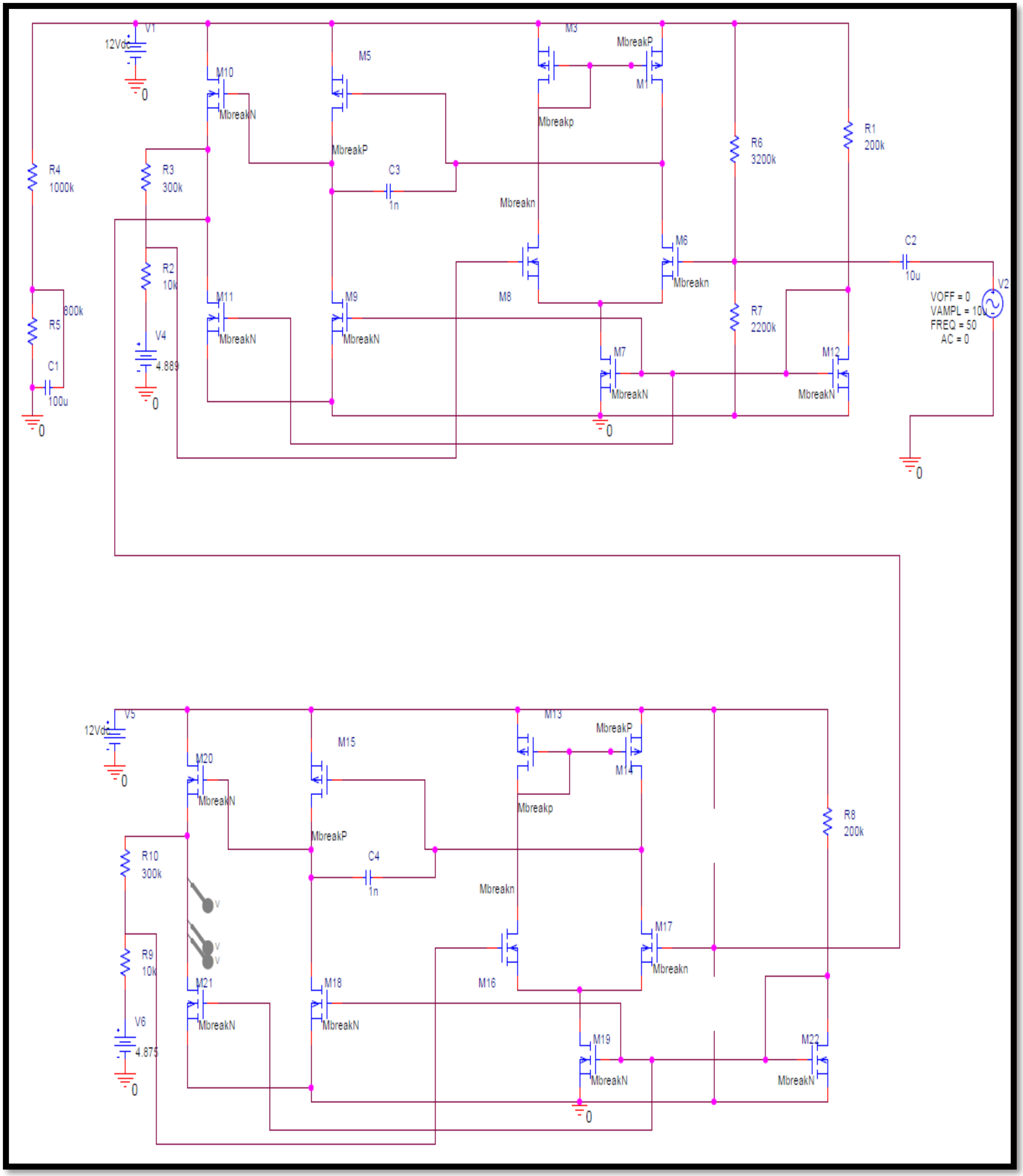
Output range- In Volts (0.5-9.5 volts)

Working-
When, input is a sin function of amplitude 5mV (Range from -5mV to 5mV).



Output Range - 0.5V to 9.5V

Circuit of Frontend Amplifier-

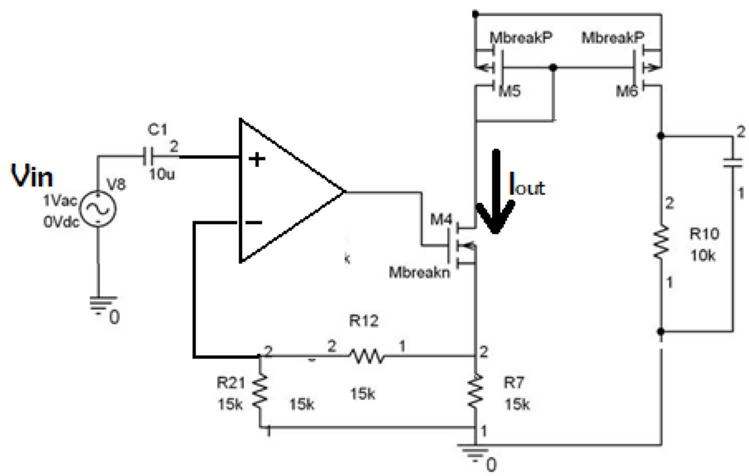


To see Pspice circuit of Frontend Amplifier, click here.

[2]- Voltage to Current converter-

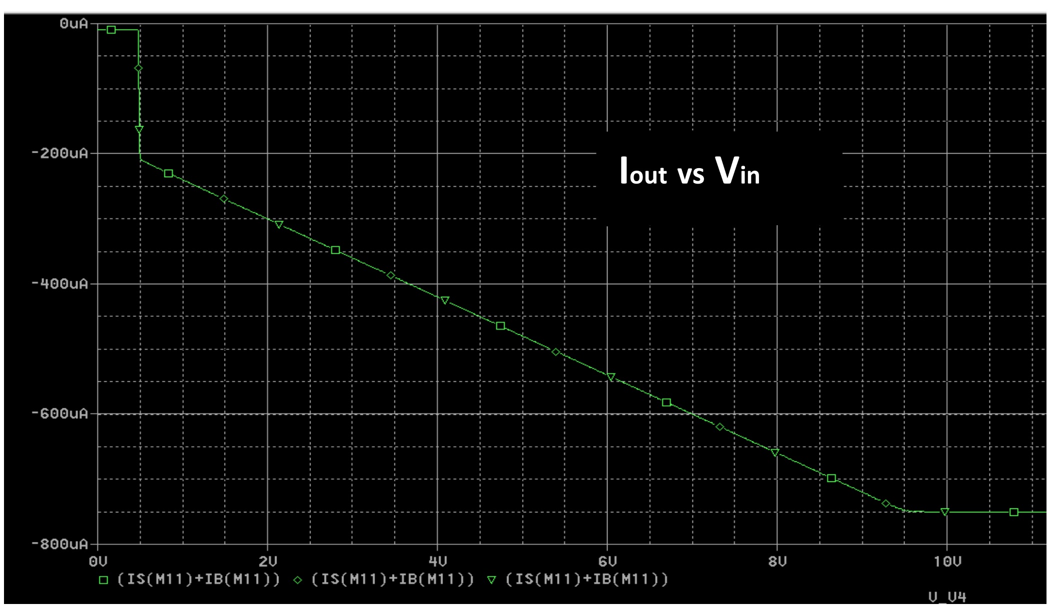
We will use CCO for ADC so, it is required that we convert our amplified ECG signal to the current in such a way that output current is proportional to the input voltage or they have a linear relation.

The overview of V to I converter circuit is given below-



The output from the frontend amplifier is feeded in V to I converter. This circuit has very high precision and accuracy. M5 and M6 act as current mirror.

Figure on below show, how output current varies w.r.t. input voltage. They are directly proportional and have a linear relation as we want.

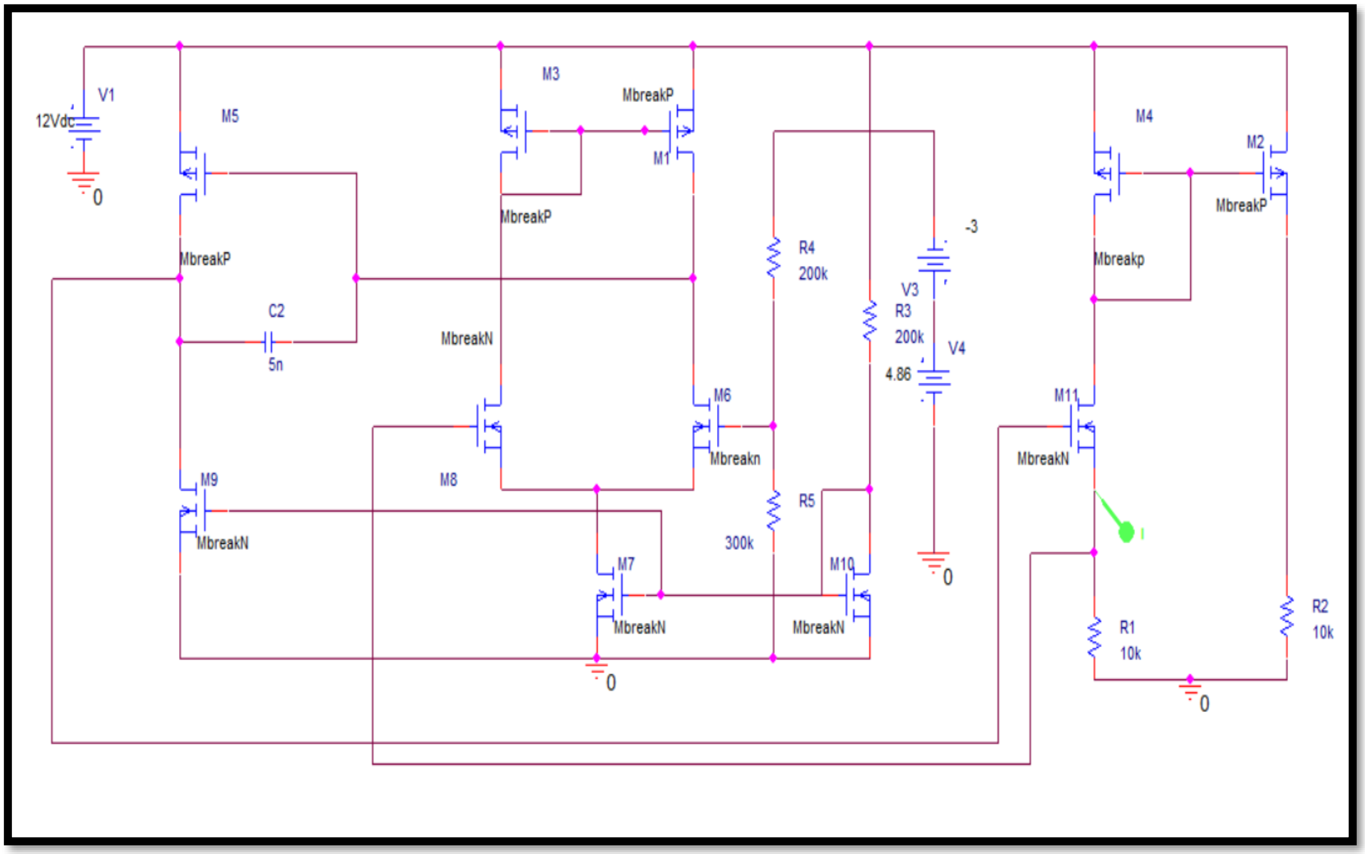


The output swing of frontend amplifier and input swing of V to I converter should be same (i.e. 0.5-9.5 volts). We achieve this feature by adding a constant voltage source with the input voltage source and by changing the value of resistances.

Input range- 0.5-9.5 volts

Output range- 200-750 uA

Circuit for V to I Converter-



To see Pspice circuit of V to I Converter, Click here.

[3]- CCO based Analog to Digital Converter (A/D)-

We will use a current controlled oscillator and then we will count the number of pulses in a fix time interval (sampling period) using a counter and the output of this counter is our digital ECG signal.

Calculating sampling Frequency-

According to **Nyquist criterion**, the **sampling frequency** should be at least twice the highest frequency contained in the signal; otherwise information about the signal will be lost. So, we assume that the maximum component of ECG signal have the maximum frequency of 25Hz. Therefore-

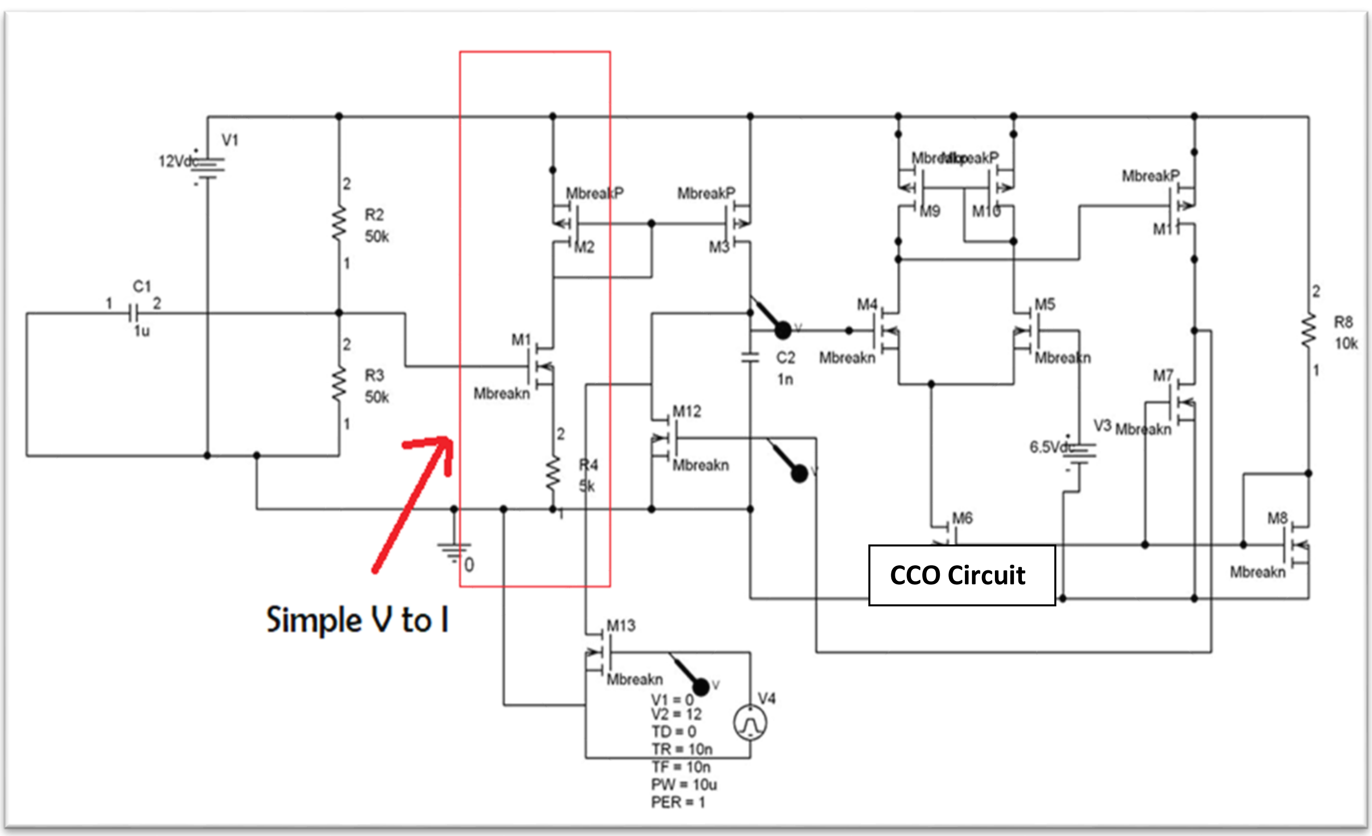
$$Sampling\ frequency = 2 \times 25Hz = 50Hz$$

$$So,\ Sampling\ Period = (1/sampling\ frequency) = 0.02\ Seconds$$

[3.1]- Current Controlled Oscillator (CCO)-

Analog to digital conversion (ADC) based on quantizing time is gaining popularity. The key circuit needed for the ADC function is a linear CCO that maps its input-signal current into a proportionate frequency. A well-known implementation for this uses a current starved ring oscillator. Though a ring oscillator produces high oscillation frequencies, its transfer characteristics are highly non-linear and sensitive to process, voltage and temperature variations (PVT). Many designs rely on digital calibration to compensate for these variations causing an increase in power dissipation and circuit complexity.

An alternate approach is to use a relaxation oscillator based on linear charging and discharging of a capacitor between two fixed voltage thresholds obtained using the well-known Schmitt trigger using positive feedback for regeneration. The charging currents are obtained using long channel-length transistors that provide nearly ideal current-sources.



The Frequency (f) of this Oscillator is given by-

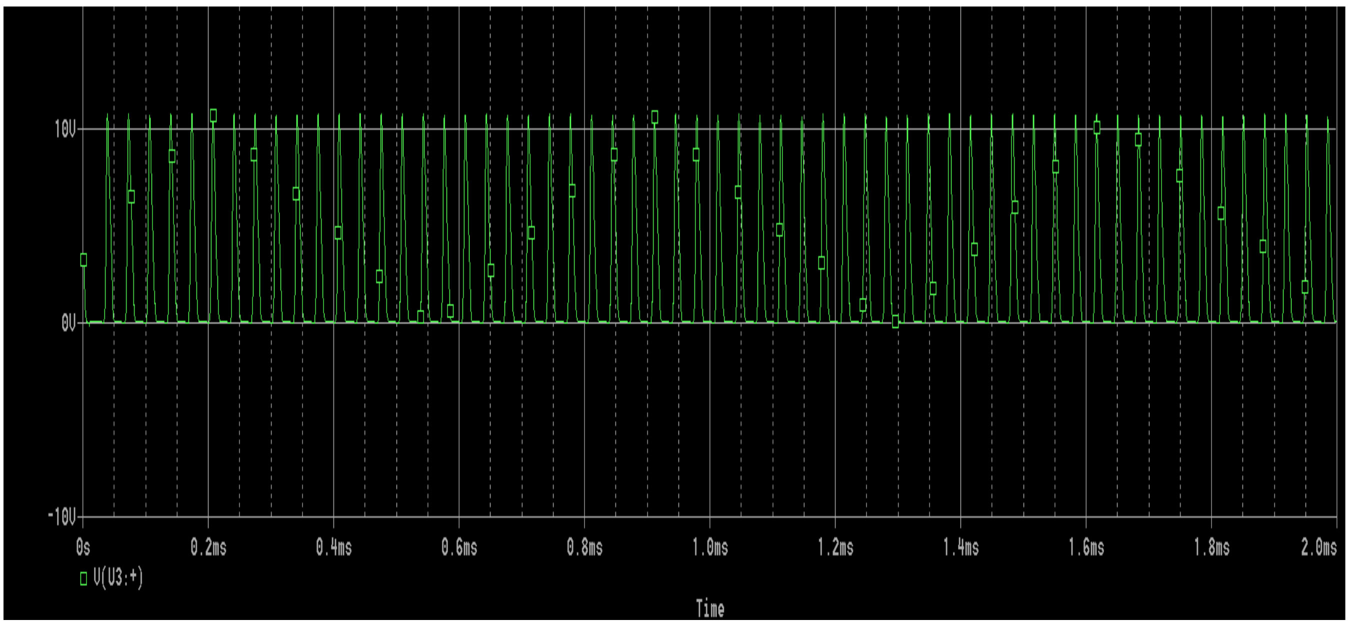
$$f = [Current\ (input) / (2C.Vref)]$$

Thus f is directly proportional to input current.

As the current ranges from 200uA to 700uA, we can get the minimum and maximum frequency corresponding to these currents.

We have given a single pulse initially to our oscillator. So that it can start the oscillation. In practical life there is no need of it because the noise present in practical circuit will cause the oscillations to start.

The Output of CCO is as follow for I = 524uA-



[3.2]- Counter-

We have use 7493A counter in Pspice simulation.

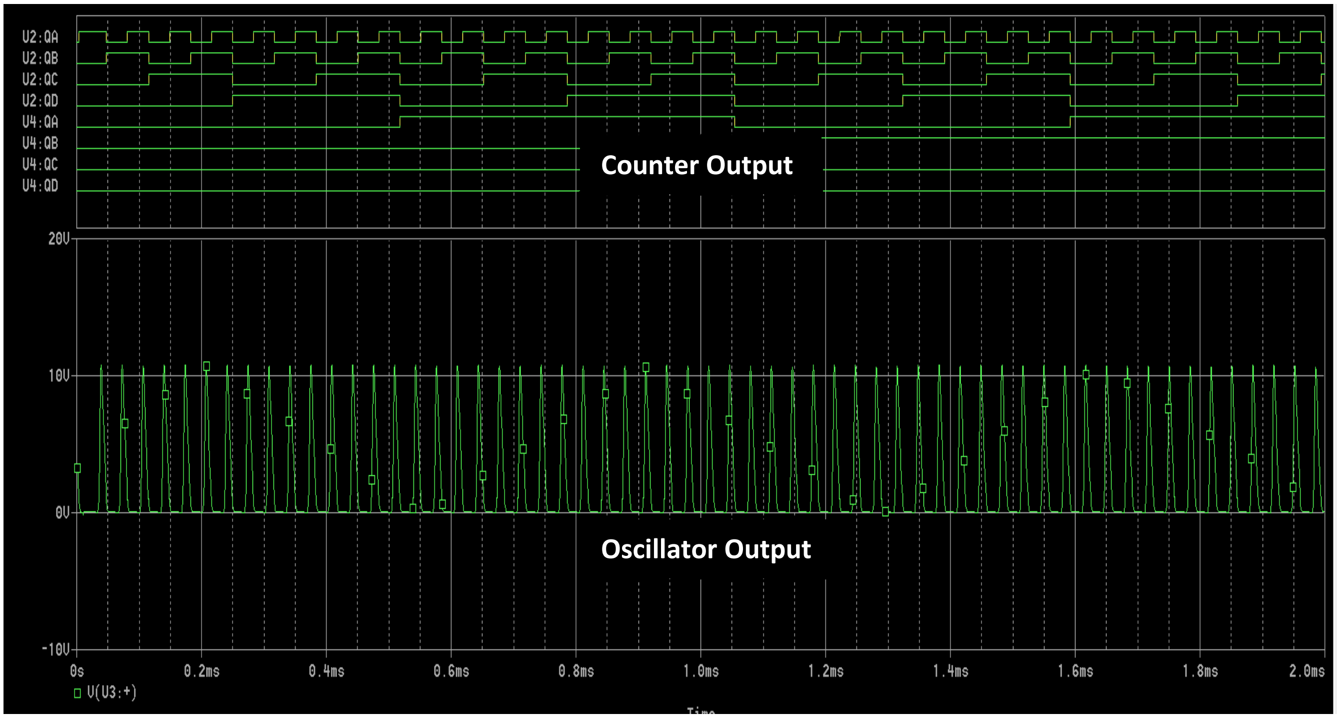
The Output of CCO is feeded as input for clock of the counter and after every 0.02 sec the counter is reset and the result is saved as digital form of ECG signal in every 0.02 sec.

The output of counter for input current, I = 524uA is shown below.

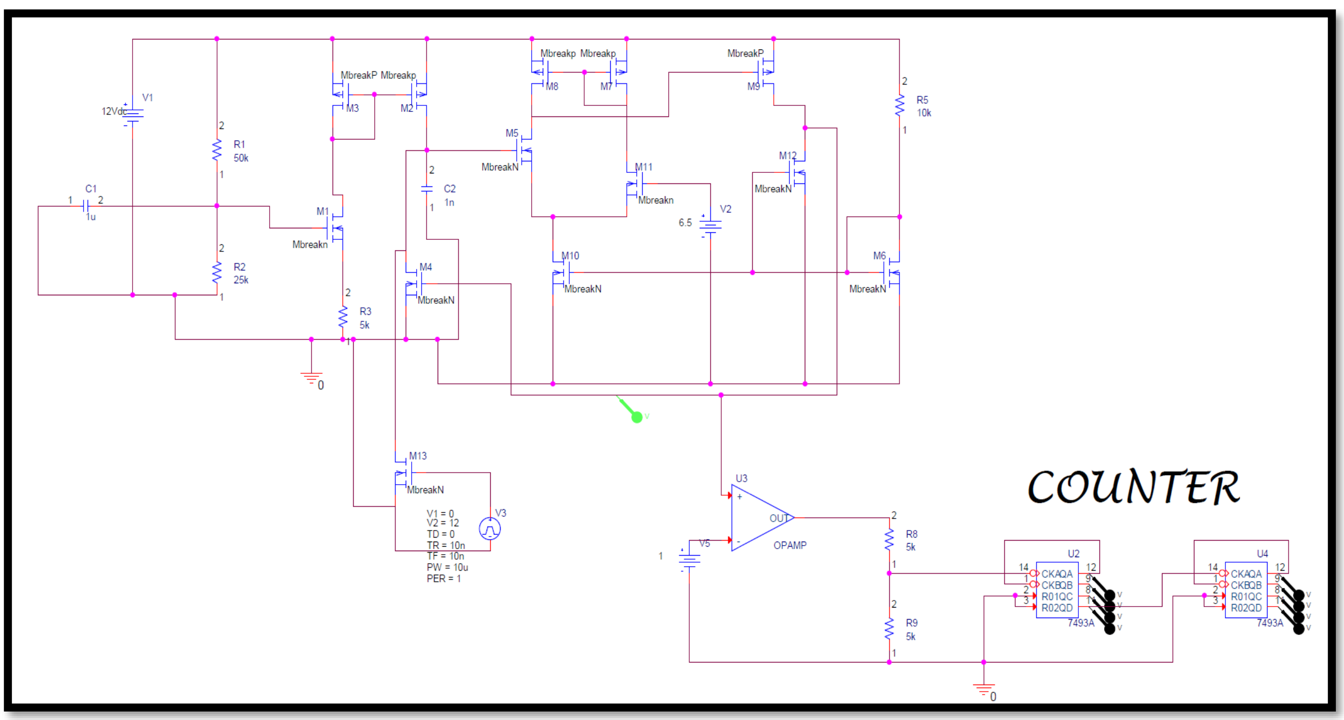
U4 : QD is MSB and U2 : QA is LSB.

The output of counter is 60 in 0.002 seconds. So the oscillator creates 60 pulses in 2ms or we can say 600 pulses in 0.02 sec (sampling period). And this is the digital value for our input ECG signal in this sampling period.

In this way we can convert ECG signal into digital signal for each sampling period.



Circuit for ADC-



To see Pspice circuit of CCO based A/D Converter, click here.

Result and Conclusion:

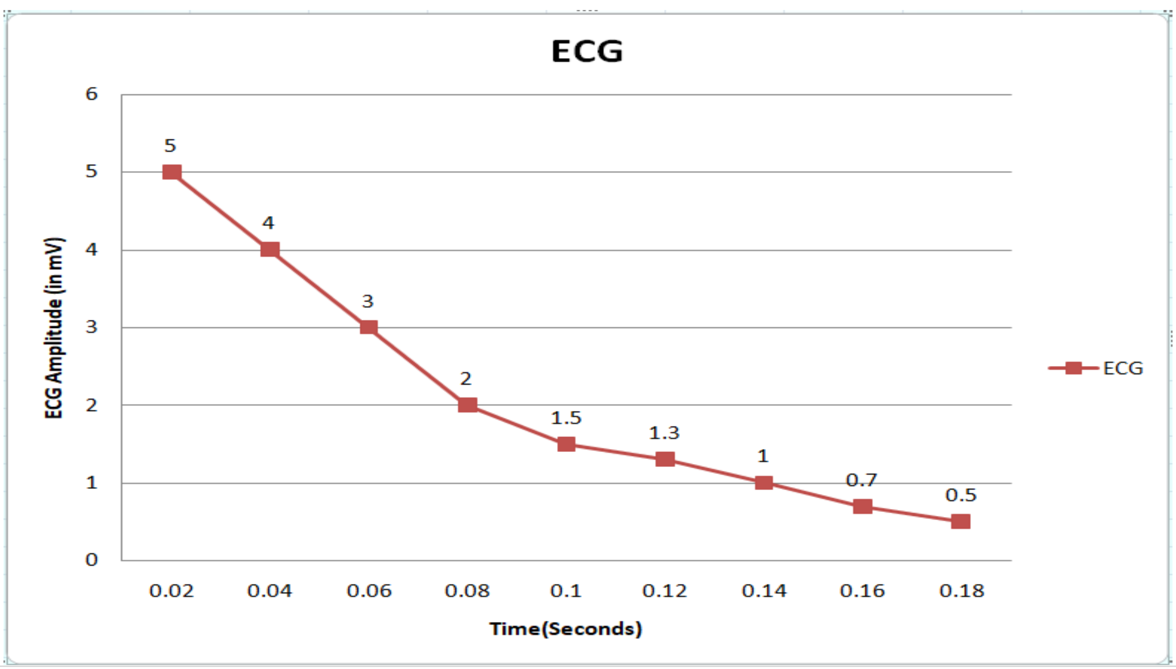
We have simulated the circuit on OrCAD Pspice as we have use student edition, so there are limitation on the size of circuit which we can simulate. So, we have to simulate the circuit in different parts, that's by it is difficult to generate a whole digital graph of ECG signal but we have find output of counter for some values of ECG signal.

Magnitude of ECG signal	Counter Output
5 mv	705
4 mv	643
3 mv	594
2 mv	528
1.5 mv	498
1.3 mv	480
1 mv	449
0.7 mv	418
0.5 mv	400

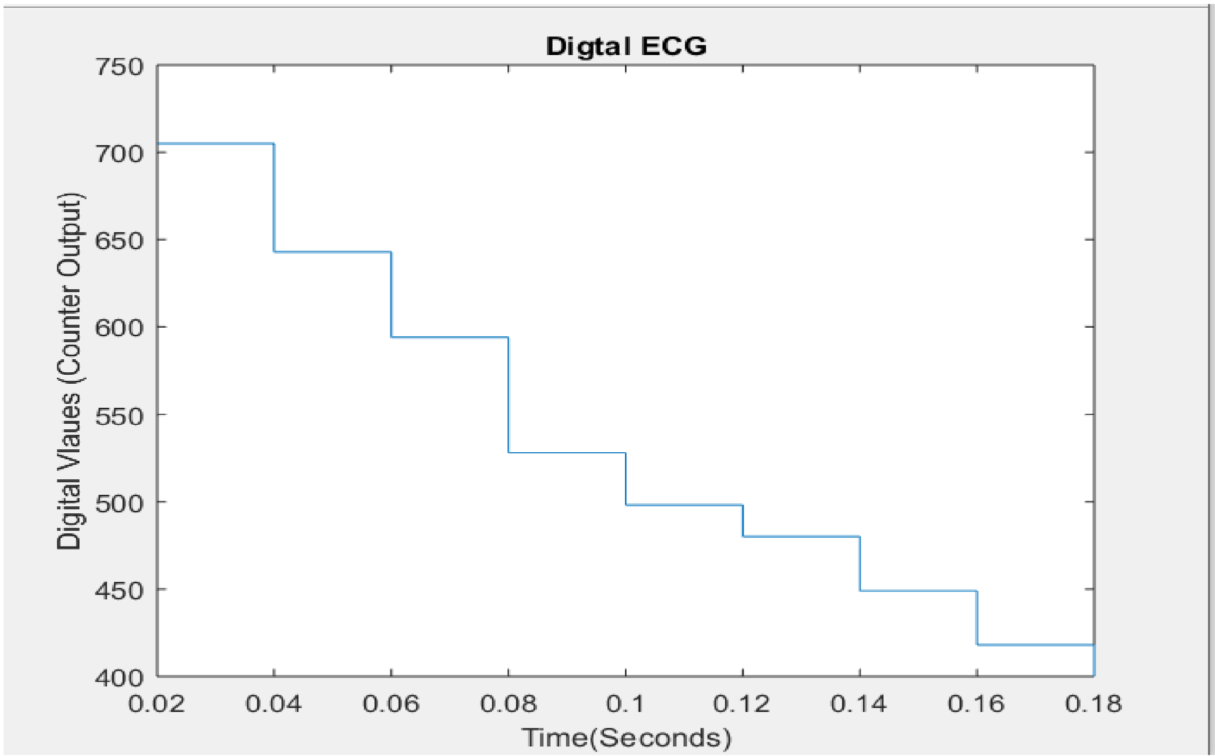
These counter values can we converted to the digital voltages.

PLOTS-

Graph of input ECG signal-



Graph of Output Digital Signal-



Reference:

[1] K.R.Raghunandan, T Lakshmi Viswanathan and Dr. T.R.Viswanathan, "Linear Current-Controlled Oscillator for Analog to Digital Conversion".

[2] Kening Wang, Shengqian Ma, Jing Feng, Weizhao Zhang, Manhong Fan, Dan Zhao, "Design of ECG Signal Acquisition System Based on DSP".

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[4] Vishnu Unnikrishnan, "Design of VCO-based ADCs".

[5] G. Angelo Virgin, Dr.M.Sangeetha, "CONVERSION OF ECG GRAPH INTO DIGITAL FORMAT AND DETECTING THE DISEASE".